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## **SYNTHETIC APERTURE LADAR FOR TACTICAL IMAGING (SALT) (BRIEFING CHARTS)**

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<b>14. ABSTRACT</b> Flight demonstrations have proven the feasibility of synthetic aperture LADAR (SAL) imaging and have produced outstanding imagery of vehicles and engineering test targets. These tests were conducted under the Synthetic Aperture LADAR for Tactical Imaging (SALTI) program. SALTI is a Defense Advanced Research Project Agency program executed with the Air Force Research Laboratory, Sensors Directorate which has demonstrated practical SAL architectures. The atmospheric and target phenomenologies were investigated for both short wave infrared (SWIR) and long wave infrared (LWIR) systems and the relevant are compared with some basic SAR parameters. An introduction to the SAL systems is presented, representative simulated images are shown and turbulence driven performance regimes are discussed. Finally, test objectives of a third series of tests and future plans are presented.						
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Strategic Technology Office

# Synthetic Aperture Ladar for Tactical Imaging (SALTI)



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# SALTI Program



**Sponsor: DARPA/STO**

**Executing Agent: AFRL, Sensors Directorate**

**Government Team: AFRL, JHU/APL, NASA/JPL, MIT/LL**

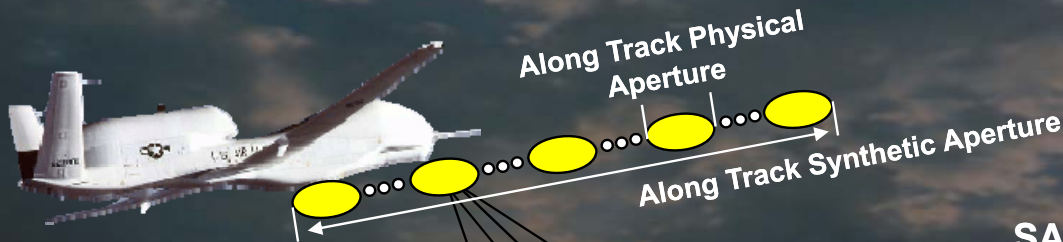
**Objective: Develop and demonstrate an airborne synthetic aperture laser radar (LADAR) imager capable of producing high-resolution, three-dimensional imagery at long ranges. Future plans are to prototype and demonstrate on military aircraft.**

**“Timelier than SAR with interpretability of an EO Sensor”**





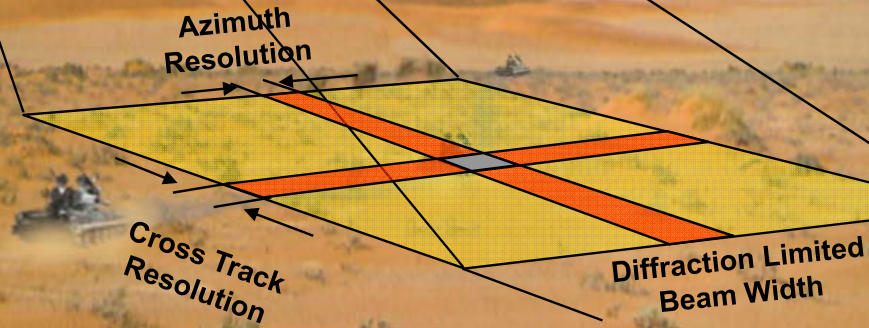
# Synthetic Aperture Basics



- Synthetic aperture imaging (SAR or SAL) uses phase history to differentiate scatterer location within a scene based upon precise knowledge of the sensor motion and the assumption that the scatterers are stationary.
- Errors in the knowledge of sensor motion and unknown target motion lead to image distortion.

## SAL/SAR Comparison

- Wavelengths are  $\sim 10000\times$  shorter than X-Band SAR
- Impacts
  - + Beamwidth  $\sim 10000\times$  less
  - + Collection time  $< 10000\times$  less
  - Motion  $\sim 10000\times$  more Sensitive (mitigated by short collection time)
  - Greater Atmospheric Sensitivity





# SAL Implementation



- Real Aperture (RA) Beam – Diffraction limited spot on Target Area

$$\theta_{RA} = \frac{\lambda}{D} R$$

$$\delta_{\alpha} = \frac{\lambda}{2L_e} R$$

- Synthetic Aperture Baseline ( $L_e=VT$ ) is the effective along track dimension of the aperture
- Synthetic Aperture (SA) image is formed Intra-beam within each individual RA beam
- SA Array – Simultaneous vertical group of RA beams, or SA images, combined to form image





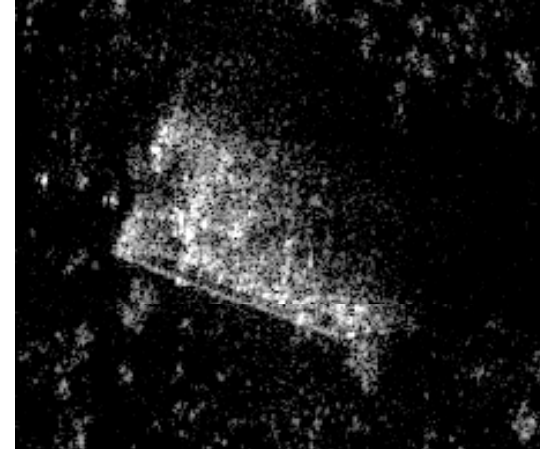
# Synthetic Aperture Ladar

## SAL – SAR Comparison

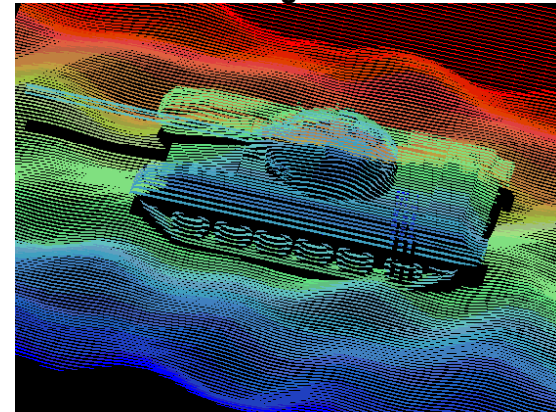


- **SAL Benefits**
  - High resolution
    - Angle resolution proportional to wavelength ( $\sim \lambda/D$  or  $\lambda/2VT$ )
    - Range resolution depends on system bandwidth
  - High interpretability
    - Scattering is more diffuse as compared to radar
    - Image quality - more like visible
  - Short Acquisition Times from 10000x shorter  $\lambda$ 
    - The price is narrow field-of-regard
- **Operational issues/features**
  - Cued from other sensor or coordinates (not a search sensor), Produces fast high resolution image of small areas
  - Day/night Operation
  - Some obscuration penetration possible, but not all weather
  - LPI
  - Exploitability of 3-D imagery
  - Avoids RF spectrum allocation problems

Actual RF SAR Image



Simulated SAL Image.



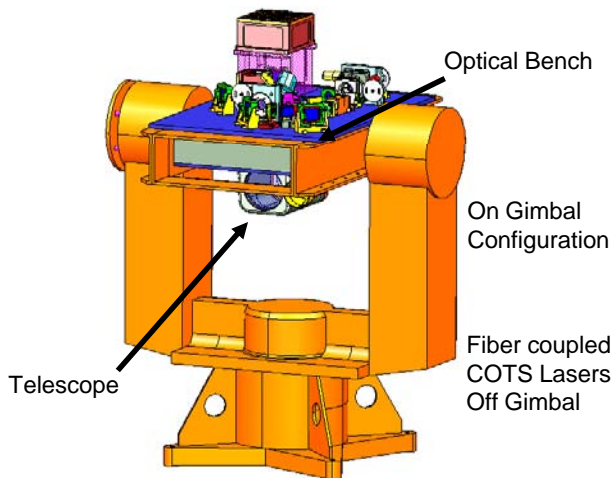




# SAL System Summaries

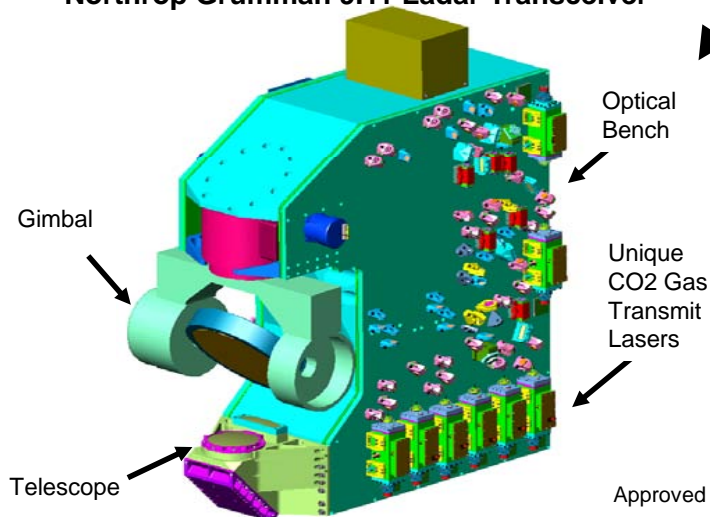


## Raytheon 1.5 $\mu\text{m}$ Fiber Laser System



- **Raytheon: 1.55  $\mu\text{m}$** 
  - COTS fiber technology
  - Multiple Tx beams
  - Stretch Processing w/ Coherent on Receive
- **Northrop Grumman: 9.11  $\mu\text{m}$** 
  - CO2 unique laser development
  - 4 Interleaved “Gatling Gun” Laser approach with single array
  - Stretch Processing w/ Coherent on Receive

## Northrop Grumman 9.11 Ladar Transceiver



- **Each approach has its advantages and disadvantages**
  - Component Availability/Scalability
  - RA Resolution –  $\lambda/D$
  - Turbulence favors larger wavelength
  - Atmospheric Transmission
  - Target Phenomenology (BDRF)

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## SALTI Significant Achievements



- Demonstrated synthetic aperture resolution, measured from corner-cube images) using different wavelengths and architectures (Spring 2006). *These were the first-ever synthetic aperture images produced from airborne sensors!*
- Produced compelling 3-D imagery of extended diffuse targets (Fall 2006)
- Demonstrated viability of SAL operation in urban setting (Long Beach, CA) including urban canyons and sides of buildings (Spring 2007)



# Challenges



- Atmospheric Turbulence
- Target Motion
  - Velocity
  - Acceleration
  - Vibration



# Atmospheric Turbulence Operating Regions

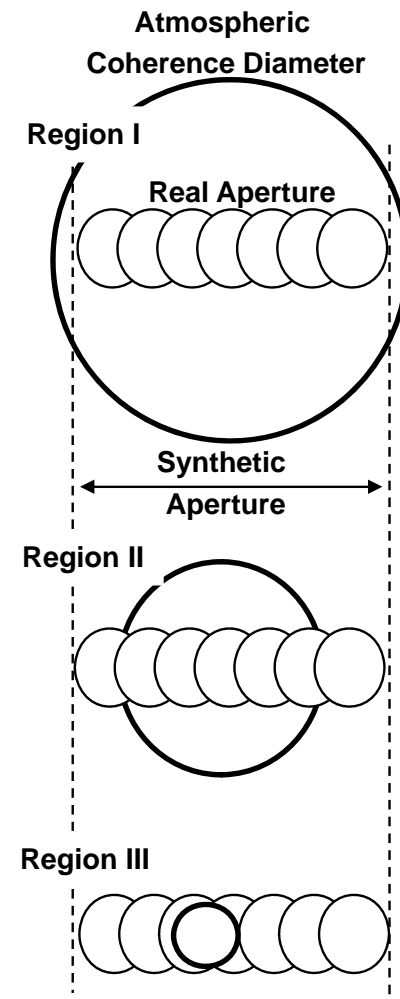


- Regions Defined by Atmospheric Coherence Diameter, the Real Aperture, and the Synthetic Aperture Length

$$r_o(R) = \left[ 0.4233 k^2 \int_0^R C_n^2(z) \left( \frac{z}{R} \right)^{5/3} dz \right]^{-3/5} \propto \lambda^{6/5} \quad \tilde{r}_0 = r_0 / 2^{6/5}$$

$$\frac{r_o}{L} \propto \frac{\lambda^{6/5}}{\frac{\lambda}{\delta}} \propto \lambda^{1/5}$$

- Weaker than expected LWIR/SWIR advantage due to increased baseline for equivalent resolutions
- Region I – Both the Real aperture and entire baseline fits within coherence diameter
  - Image formation – No impact
  - Efficiency - No impact
- Region II – Each Real aperture fits within coherence diameter, but not Baseline
  - Image formation – Each real aperture is coherent, but not coherent across SA. SA image can still be formed with processing - & Auto focus.
  - Efficiency – No Impact
- Region III Aperture – Coherence Diameter Smaller than both baseline and Real Aperture
  - Image formation - RA degraded, SA difficult or impossible to form.
  - Efficiency – Degrades as the ratio of the RA to Coherence Diameter

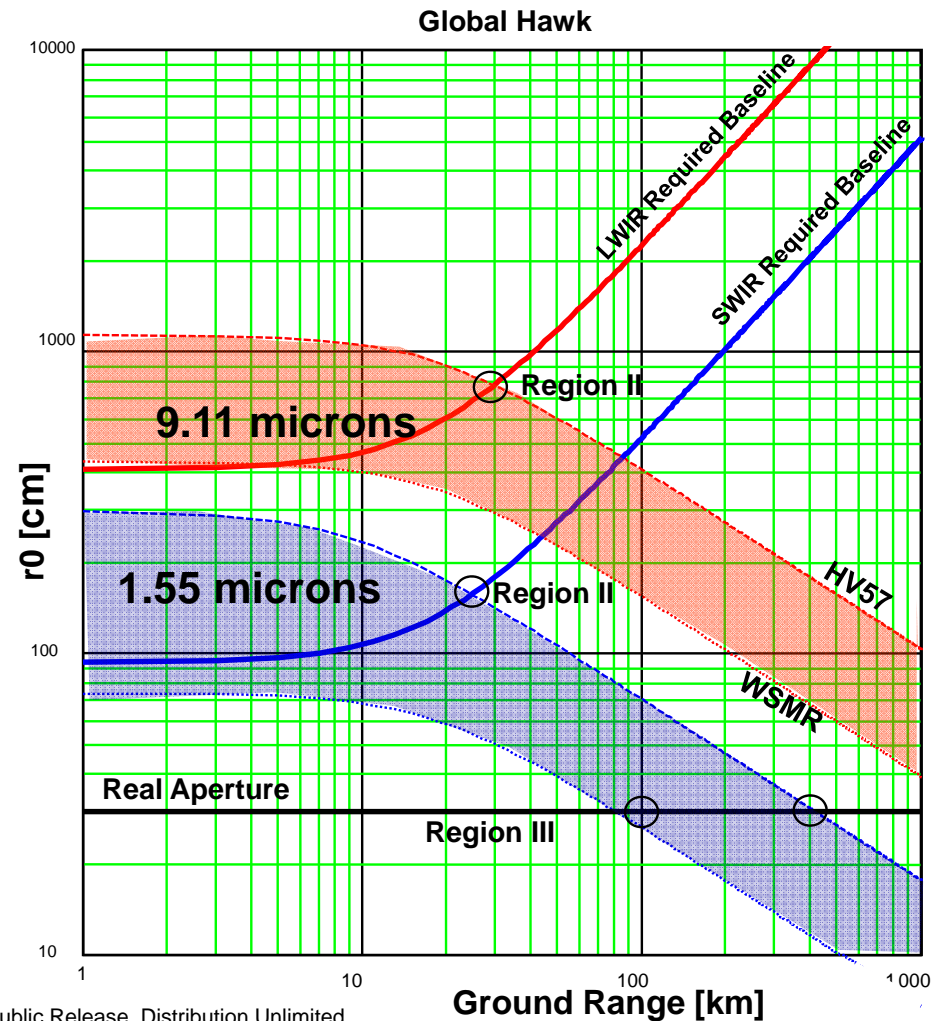




# Atmospheric Turbulence GLOBAL HAWK Case



- Coherence diameter  $r_0$  is calculated for each wavelength for best and worse case atmospheres - HV 5/7 and WSMR respectively
- Both Systems enter Region II where  $r_0$  crosses the required baseline
  - Baseline for LWIR  $\lambda_2/\lambda_1$  greater than SWIR (~6x)
  - Both systems enter Region II at about the same ranges for most atmospheres
- The Systems cross into Region III based on RA
  - SWIR crosses to Region III, but at ranges useful for GH
  - LWIR does not at practical ranges from this altitude
- SWIR may be atmospheric turbulence limited at long ranges and lower altitudes



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## Equations of Error Due to Target Motion



- **Range Error**

$$\Delta R = \dot{R} \tau c / B \lambda$$

$\dot{R}$  = target range rate

$\tau$  = pulse width

$c$  = speed of light

$B$  = chirp bandwidth

$\lambda$  = wavelength

- **Azimuth Error**

$$\Delta X = R \cdot \left( \dot{R} / V_{A/C} \right)$$

$\dot{R}$  = target range rate

$R$  = slant range

$V_{A/C}$  = Aircraft velocity

- **Defocusing**

$$N_{Smear} = \frac{\ddot{R} R^2 \lambda}{2 V_{A/C}^2 \Delta X^2}$$

$\ddot{R}$  = target range acceleration

$R$  = slant range

$V_{A/C}$  = Aircraft velocity

$\Delta X$  = azimuth resolution

For  $N_{Smear} = 1$ ,

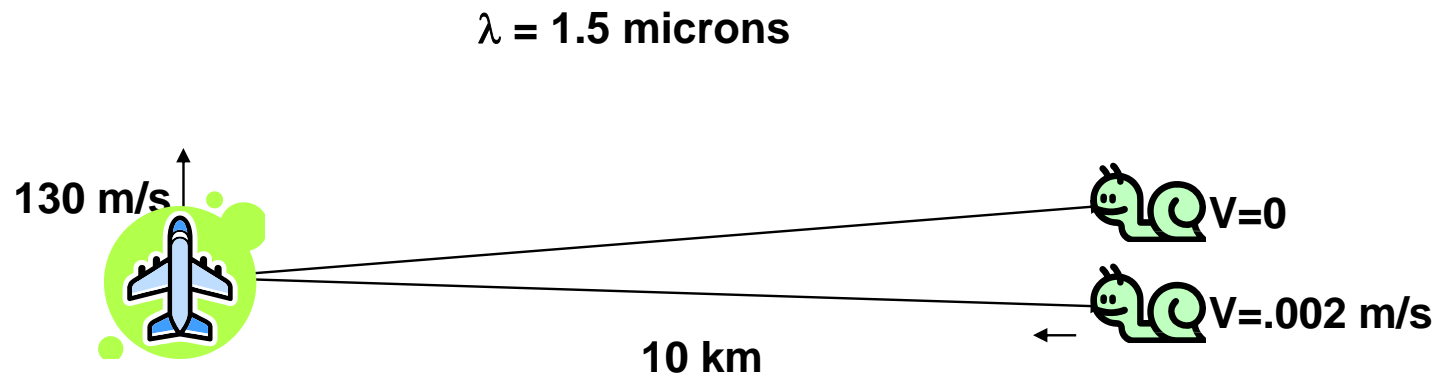
$$\ddot{R}_{min} = \frac{2 V_{A/C}^2 \Delta X^2}{R^2 \lambda}$$



## Snails Example



Suppose you have two snails separated by 15 centimeters in azimuth. They would occupy the same “real” beam but should be easily resolvable in the SAL image. Assume they are distinguishable by their contrast above/below the dirt return. Assume one is stationary and one is crawling toward the sensor at the rate of 2 mm/sec. In this case, the two snails appear at **exactly the same azimuth in the image**.



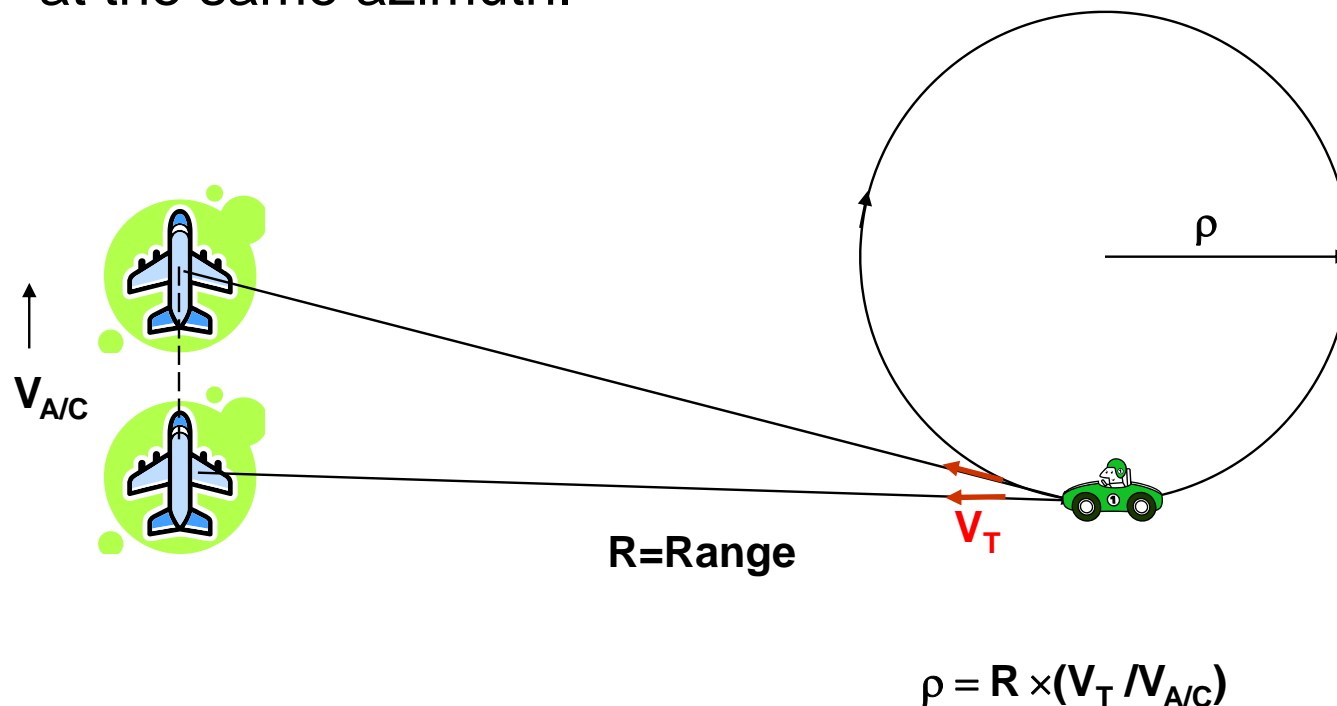
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## Slow Turn



- Suppose a vehicle in the scene is making a very slow turn such that its velocity vector is always toward the sensor; then, every scatterer on the vehicle would appear at the same azimuth.



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## Summary



- **SALTI sensors are the first-ever synthetic aperture LADAR to be operated from aircraft.**
  - Two parallel and independent systems with different wavelengths and architectures
  - Range, azimuth, and elevation resolutions match theoretical predictions
  - Unprecedented 3D renderings of extended diffuse targets
  - Unlike SAR (radar), can operate in urban settings
- **Effects of target motion/acceleration and atmospheric turbulence are under investigation.**